



“Systems Engineering Essentials”

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Agenda

- I. Why do we need Systems Engineering?
- II. What is Systems Engineering?
- III. When do we use Systems Engineering?
- IV. Who is the Systems Engineer?
- V. Where do we apply Systems Engineering?
- VI. What are the important components of Systems Engineering?
- VII. How can we incorporate Systems Engineering into our environment?

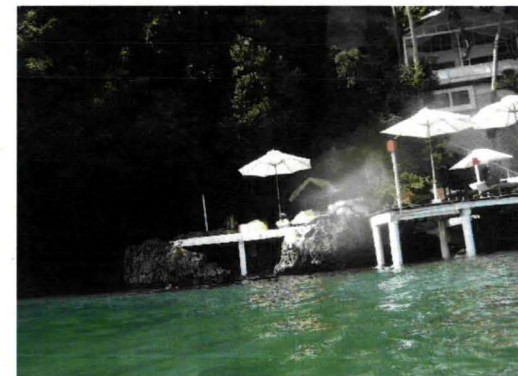
Prerequisite Exercise



Imagine you wanted to design and build a backyard deck.

- How would you tackle the problem?
- What things do you need to think about?

Backyard Systems Engineering



**Another Question: How would you design and build a deck for space?
Is the process different? Is the Environment Different?**

I. Why do we need Systems Engineering?



Group Question:

Why do we need Systems Engineering?

“For time and the world do not stand still. Change is the law of life, and those who look only to the past or the present are certain to miss the future.” John F. Kennedy, 35th President of the United States.

I. Why do we need Systems Engineering?



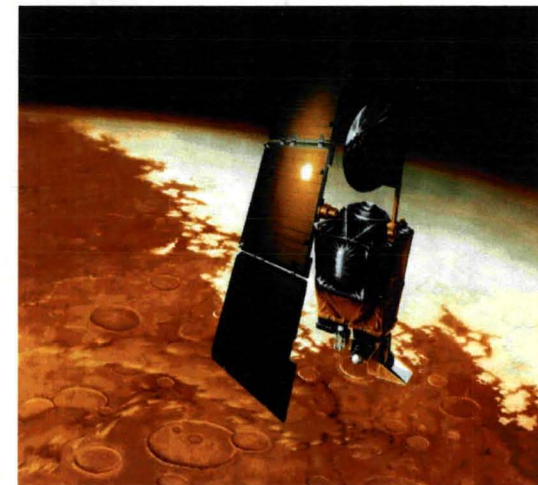
- Why the Mars Climate Orbiter went off Course during Mars orbit insertion?
 - <http://www.jamesoberg.com/mars/loss.html>
- Primary Science Objective: observe and study dust storms, weather systems, clouds and dust hazes, ozone, distribution and transport of dust and water, the effects of topography on atmospheric circulation, atmospheric response to solar heating, and surface features, wind streaks, erosion, and color changes.
- Secondary Objective: serve as a data relay satellite for the Mars Polar Lander and other future NASA and international lander missions to Mars.



NASA JPL Development –
Development Cost \$193M
(Dev began around 1995)



Delta II Lite with 4 Strap-on Solid
Rocket boosters & Star 48 third stage
(December 11, 1998 Complex-17 Pad A
@ 1:45EST) – Launch Cost - \$91.7M

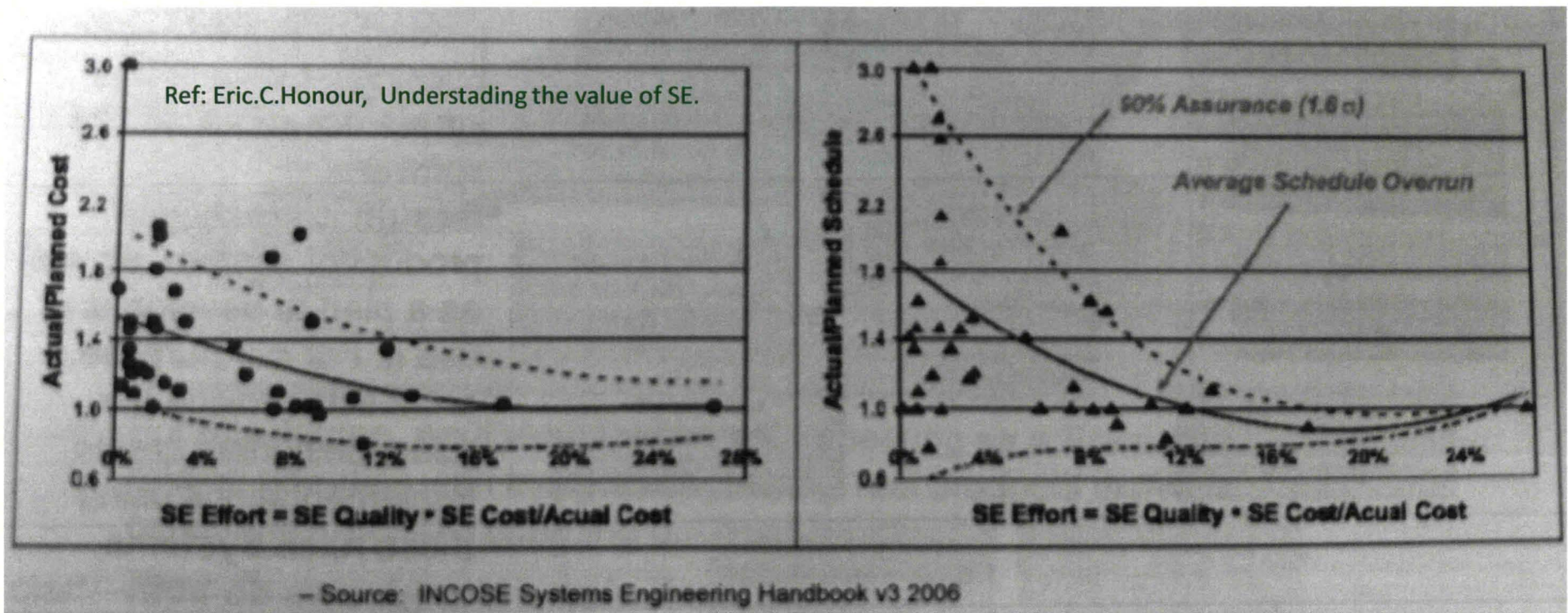


Crashed on September 23, 1999.
Findings of the failure review board
indicate that **a navigation error
resulted from some spacecraft data
being reported in Imperial units
instead of metric.** – Ops Cost -
\$42.8M, Total Cost - \$327.6M

I. Why do we need Systems Engineering?



Q: If there is no Systems Engineering, what are the impacts to Cost and Schedule?

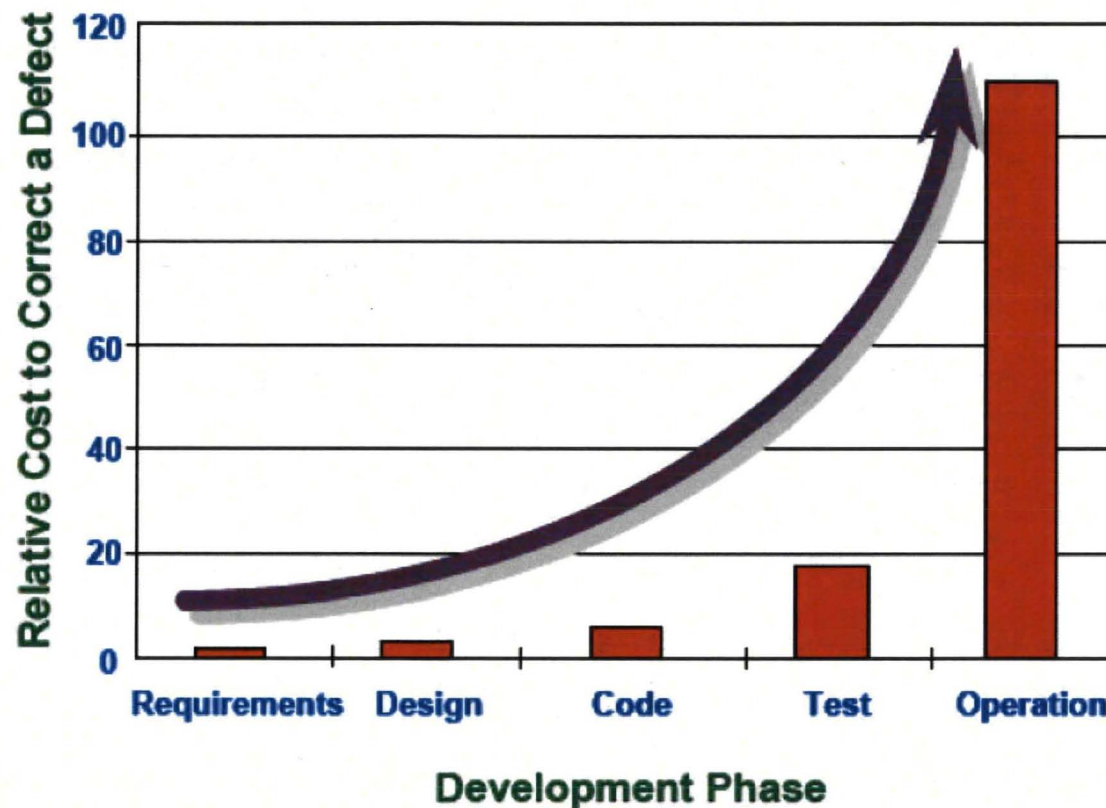


Yes, Cost and Schedule overruns are correlated with Systems Engineering efforts. -> **Pay now or pay later.**

I. Why do we need Systems Engineering?



The Real Cost of Software Defects



The earlier you find a software defect, the lower the cost to repair.

I. Why do we need Systems Engineering?



**Zombie Satellite Forces More
Evasive Maneuvers for Other Craft**

By **Peter B. de Selding**

Space News

posted: 20 July 2010

05:20 pm ET

Galaxy 15

PARIS — Satellite fleet operator Intelsat has successfully negotiated the passage of its out-of-control Galaxy 15 satellite across the path of its Galaxy 13 spacecraft with no signal interruption for Galaxy 13 customers in the second of what likely will be at least four such maneuvers before Galaxy 15 shuts down on its own in August, Intelsat said.

Galaxy 15 stopped responding to commands in April and has since been drifting eastward along the geostationary arc 36,000 kilometers above the equator. Industry officials say it is the first time an uncontrolled satellite has remained electronically active, its transponders still looking for signals to rebroadcast even as it strays far from its assigned orbital position.

Galaxy 15 traveled through the orbital slot of Luxembourg-based SES's AMC-11 satellite in mid-May. That event caused no service disruptions as Intelsat and SES took measures that included routing some AMC-11 traffic through a 19-meter-diameter antenna at Intelsat's Clarksburg, Md., teleport.

Unable to shut the satellite down, Intelsat officials then prepared for the Galaxy 13 fly-by July 12-13, using some of the same interference-avoidance techniques developed for the AMC-11 encounter.

The procedure was completed "without incident," Intelsat Chief Technical Officer Thierry Guillemain said in a July 15 statement. "We will now be implementing the interference-mitigation plan for the fly-by of Galaxy 14, expected to occur at the end of July."

Luxembourg- and Washington-based Intelsat said that at one point during the Galaxy 15 transit through the Galaxy 13 orbital slot, the two satellites were within 0.05 degrees of separation. Some customers continued to use the Galaxy 13 and were able to do so because the satellite's signal reception had been reset as low as possible to permit signals to be sent without attracting Galaxy 15's interest.

Unlike AMC-11, Galaxy 13 also carries Ku-band transponders in addition to its C-band payload, meaning Intelsat was limited in its ability to move the satellite to the extreme eastern edge of its orbital slot to avoid Galaxy 15 before performing a "leapfrog" maneuver back westward as Galaxy 15 continued its eastward move.

Galaxy 15 is on course to enter the Galaxy 14 orbital neighborhood in late July, with a peak interference threat expected July 30, according to Intelsat. In mid-August, it will be Galaxy 18's turn to avoid Galaxy 15.

Intelsat officials are hopeful that sometime in mid-August, Galaxy 15, whose attitude control is slowly degrading, will lose its lock on the sun. Its power will then drain and the satellite will shut down on its own.

Intelsat is already preparing customers using Galaxy 23 for a similar avoidance procedure in late August in the event Galaxy 15 is still active by then. The company has also begun coordinating with satellite fleet operator Telesat of Canada, whose Anik F3 satellite will have to contend with Galaxy 15 in mid-September.

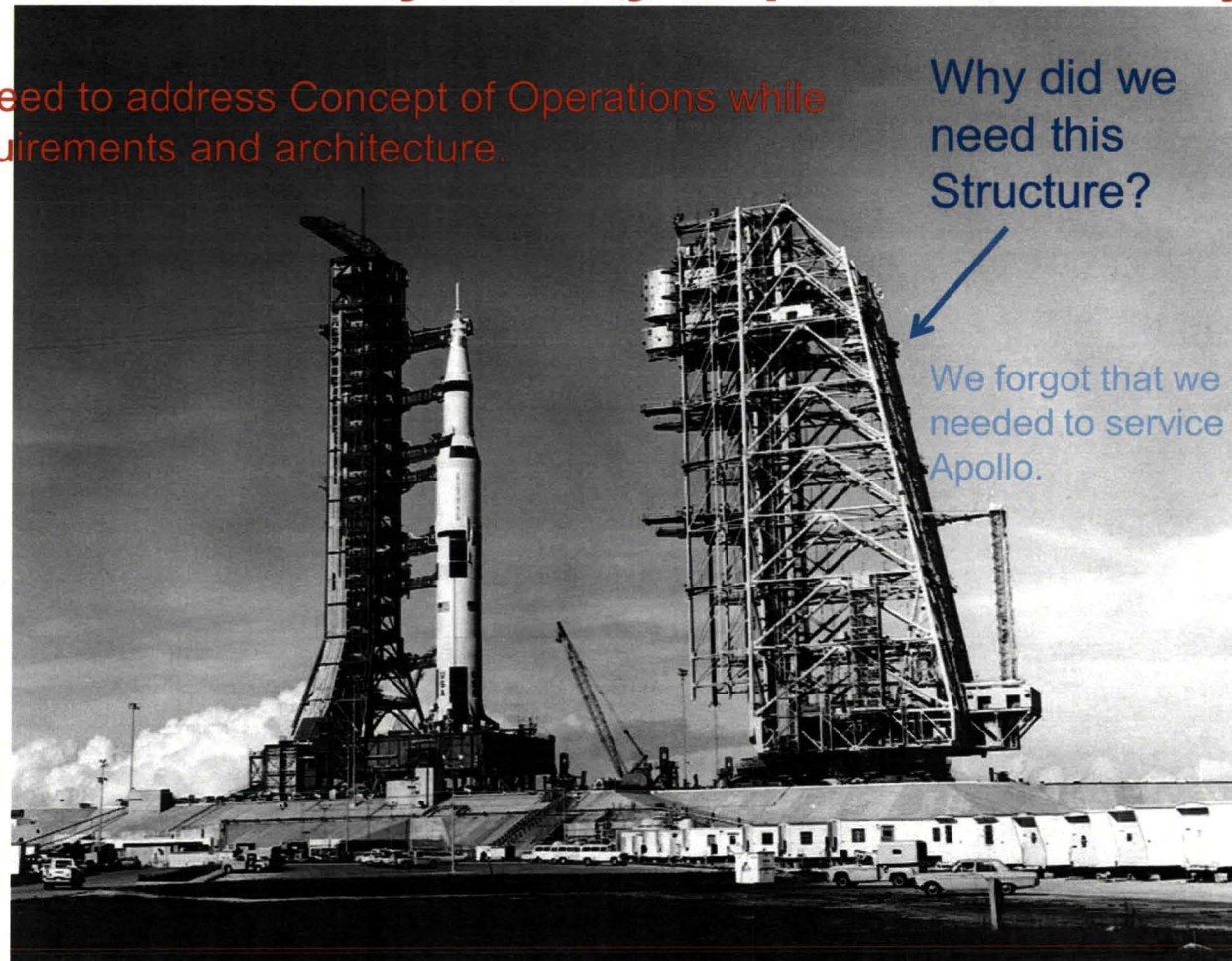
Systems Engineering needs to view the problem from the entire lifecycle.

I. Why do we need Systems Engineering?



What happens to your architecture when you don't address all of your key requirements early?

Bottom Line: Need to address Concept of Operations while developing requirements and architecture.



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Systems Engineering Essentials

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I. Why do we need Systems Engineering?

SE Essential #1

There are hundreds of good reasons why we need Systems Engineering. Such as:

- Improving Safety
- Affordable System
- Reducing Complexity
- Simple Architecture
- Ensuring Mission Success
- Resource Constraints
- Improving Competitiveness
- Operations
- Improving Productivity
- Compatibility / Consistency
- Communication
- Reuse
- Scope changes
- System Lifecycle
-

A good systems engineer can do a barium trace of the entire project with any input or change. For example, if someone says, "Here comes x," a good systems engineer immediately takes x and mentally flows it through the project and knows every soft spot that responds to that change. Mathematically, a good systems engineer knows the partial derivative of everything with respect to everything else!

*Gentry Lee,
Jet Propulsion Laboratory*

- Simply stated, **we just can't afford not performing Systems Engineering!**
- **Systems Thinking is crucial to mission success.**

***"You can see a lot by observing"* – Yogi Berra**

II. What is Systems Engineering?



Group Question:

Define Systems Engineering?

One of the biggest challenges for a systems engineer of a large complex project is to “bring order from chaos.”

*Chris Hardcastle,
Systems Engineering and Integration
Manager, NASA's Constellation Program,
Johnson Space Center*

II. What is Systems Engineering?



- A System is
 - The combination of elements that function together to produce the capability to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. NPR 7123.1
- A Subsystem is
 - A major part of a system which itself has the characteristics of a system, that is, a system that is part of some larger system.
- Engineering is
 - The application of scientific principles to practical ends; as the design, construction, and operation of efficient and economical structures, equipment, and systems. (Ref #8)
- Systems Engineering is defined as
 - Standards – INCOSE, Space & Missile System Center (SMC)
 - SE Handbook & Primer, NPR 7123.1

II. What is Systems Engineering?

SE Essential #2

- Systems Engineering is
 - Process of turning a **need** into a **capability**.
 - First and foremost about **getting the right design (vs getting the design right (meeting requirements))** and then about maintaining and enhancing its technical integrity, as well as managing complexity with good processes.
 - Looking at the **Big Picture** from the outside-in and inside-out.
 - The function of Systems Engineering is to **guide the engineering** of complex systems.

Definition: *System Engineering* is a logical structured engineering approach for formulating the problem and transform the customer need into a useful capability throughout it's entire lifecycle. J.L.Garcia

Neither the world's greatest design, poorly implemented – nor a poor design, brilliantly implemented – is worth having.⁶

III. When do we use Systems Engineering?

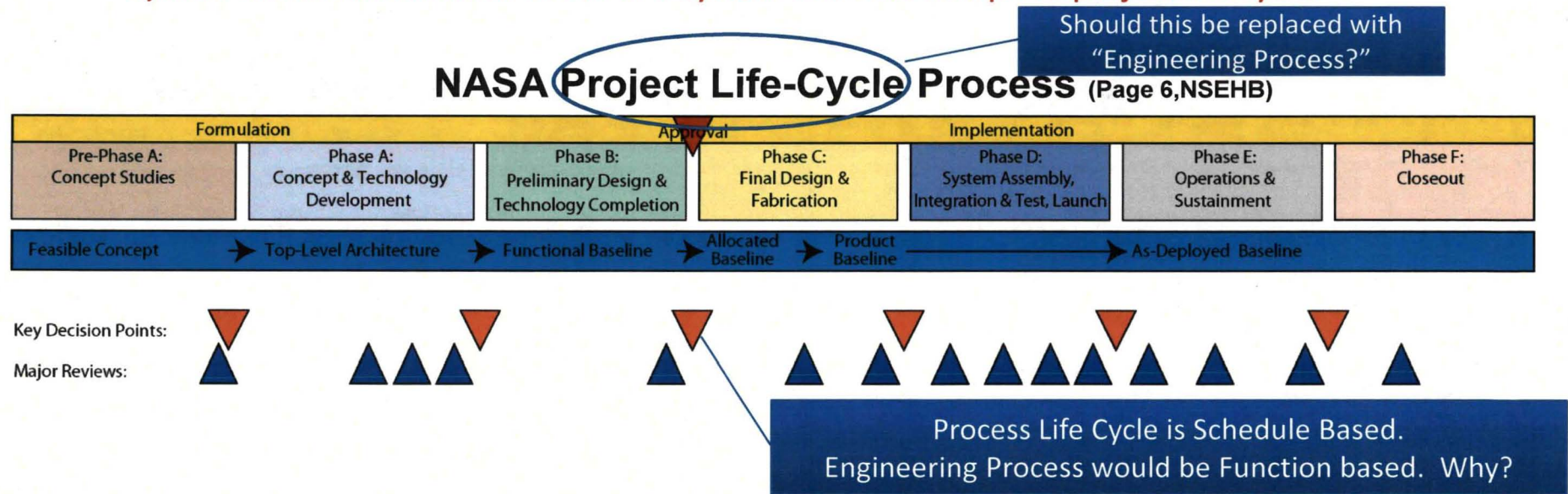


Group Question:

When do we use Systems Engineering?

III. When do we use Systems Engineering?

- NPR 7123.1, NASA SYSTEMS ENGINEERING PROCESSES AND REQUIREMENTS.
 - The purpose of this document is to clearly articulate and establish the requirements on the implementing organization for performing, supporting, and evaluating systems engineering. *Systems engineering* is a logical systems approach performed by multidisciplinary teams to engineer and integrate NASA's systems to ensure NASA products meet customers' needs. Implementation of this systems approach will enhance NASA's core engineering, management, and scientific capabilities and processes to ensure safety and mission success, increase performance, and reduce cost. *This systems approach is applied to all elements of a system and all hierarchical levels of a system over the complete project life cycle.*



III. When do we use Systems Engineering?



NASA Project Life-Cycle Phases (Page 7, NSEHB)

	Phase	Purpose	Typical Output
Formulation	Pre-Phase A Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
	Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Implementation	Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

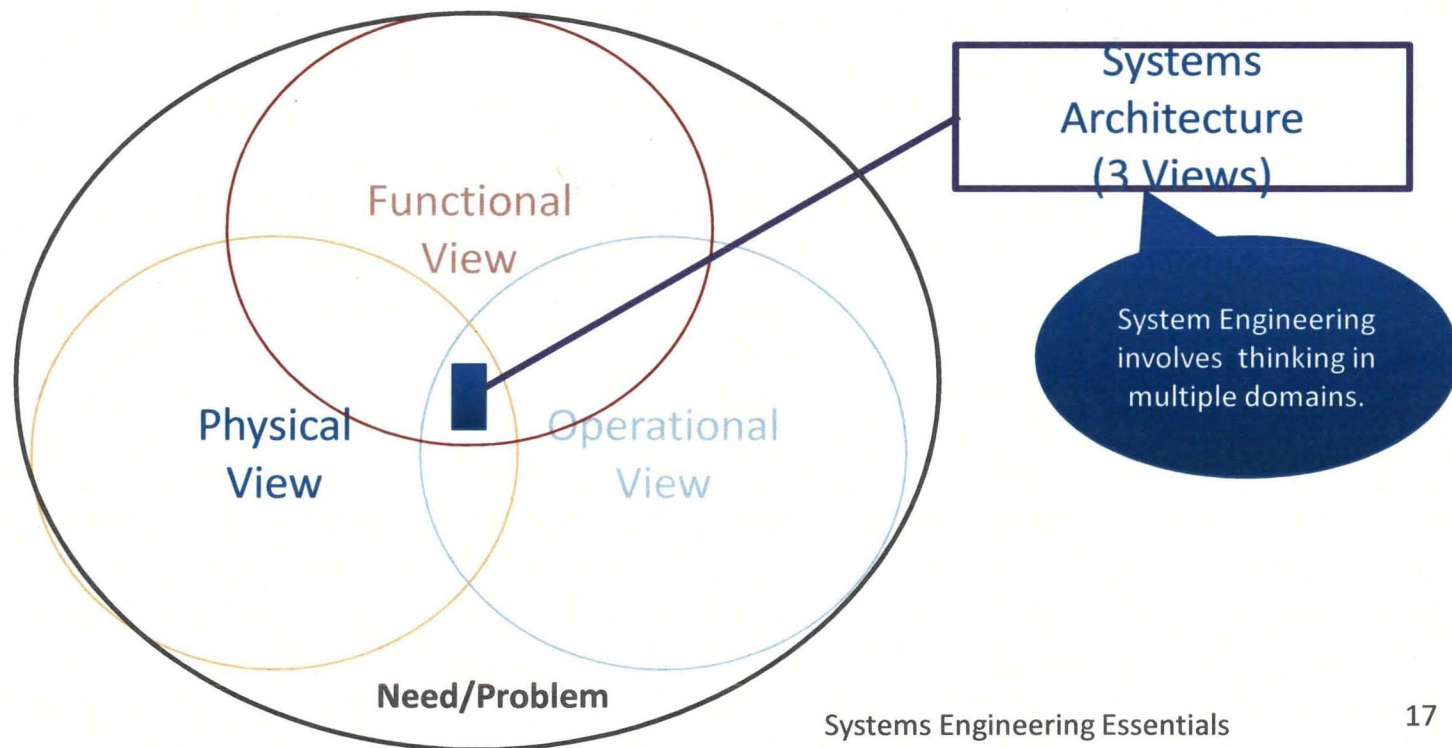
Engineering Life Cycle Functions



III. When do we use Systems Engineering?

SE Essential #3

- When do we use Systems Engineering?
 - All the time! When speak and think!
 - Throughout the Engineering and Project lifecycle.



IV. Who is the Systems Engineer?



Group Question:

Who is the Systems Engineer (SE)?

IV. Who is the Systems Engineer?



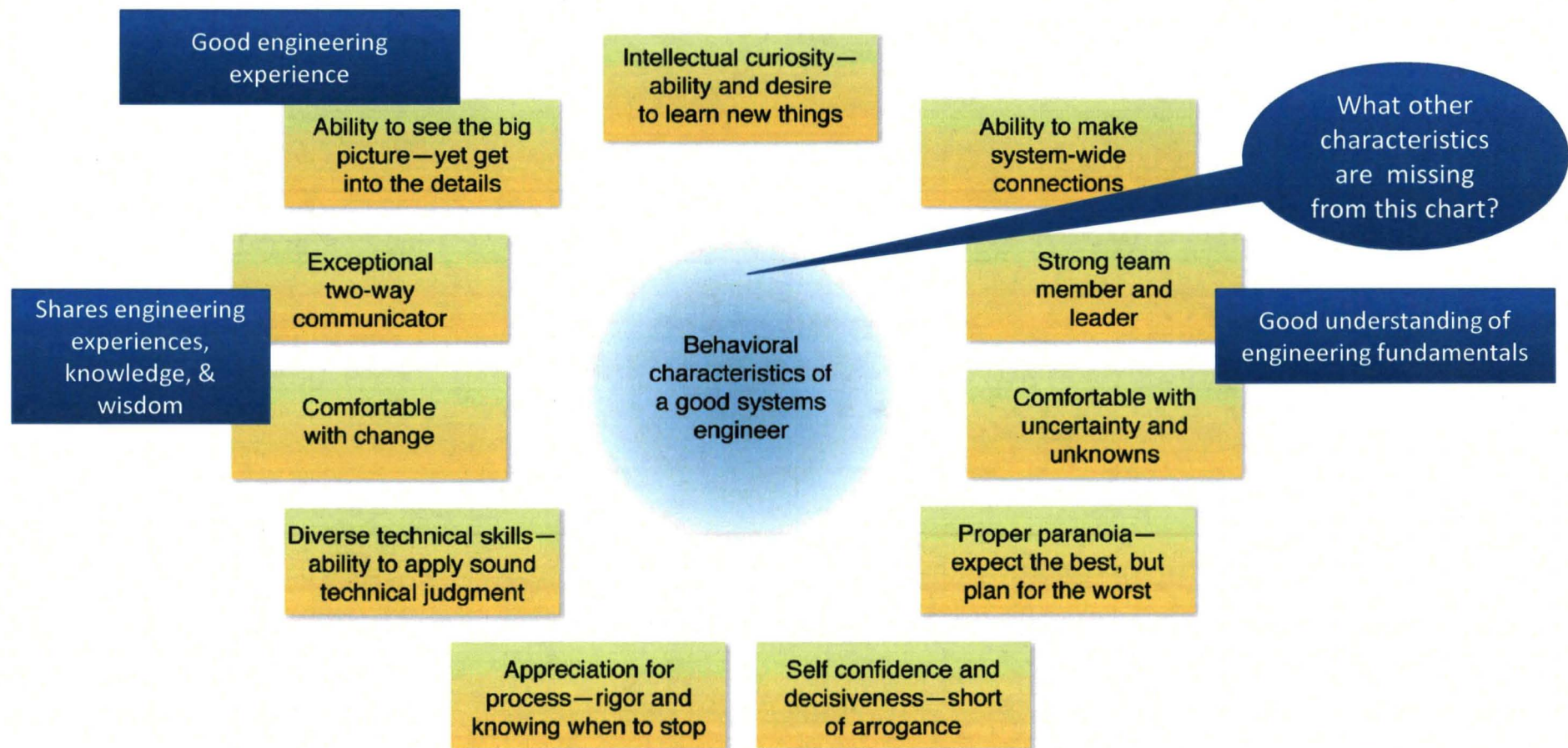
In order to answer this question, we first need to understand what the Systems Engineer does?

- Herding Cats.
 - http://www.youtube.com/watch_popup?v=Pk7yqlTMvp8&vq=large

IV. Who is the Systems Engineer?



Secondly, we need to understand the
Characteristics of Good Systems Engineer (SE).

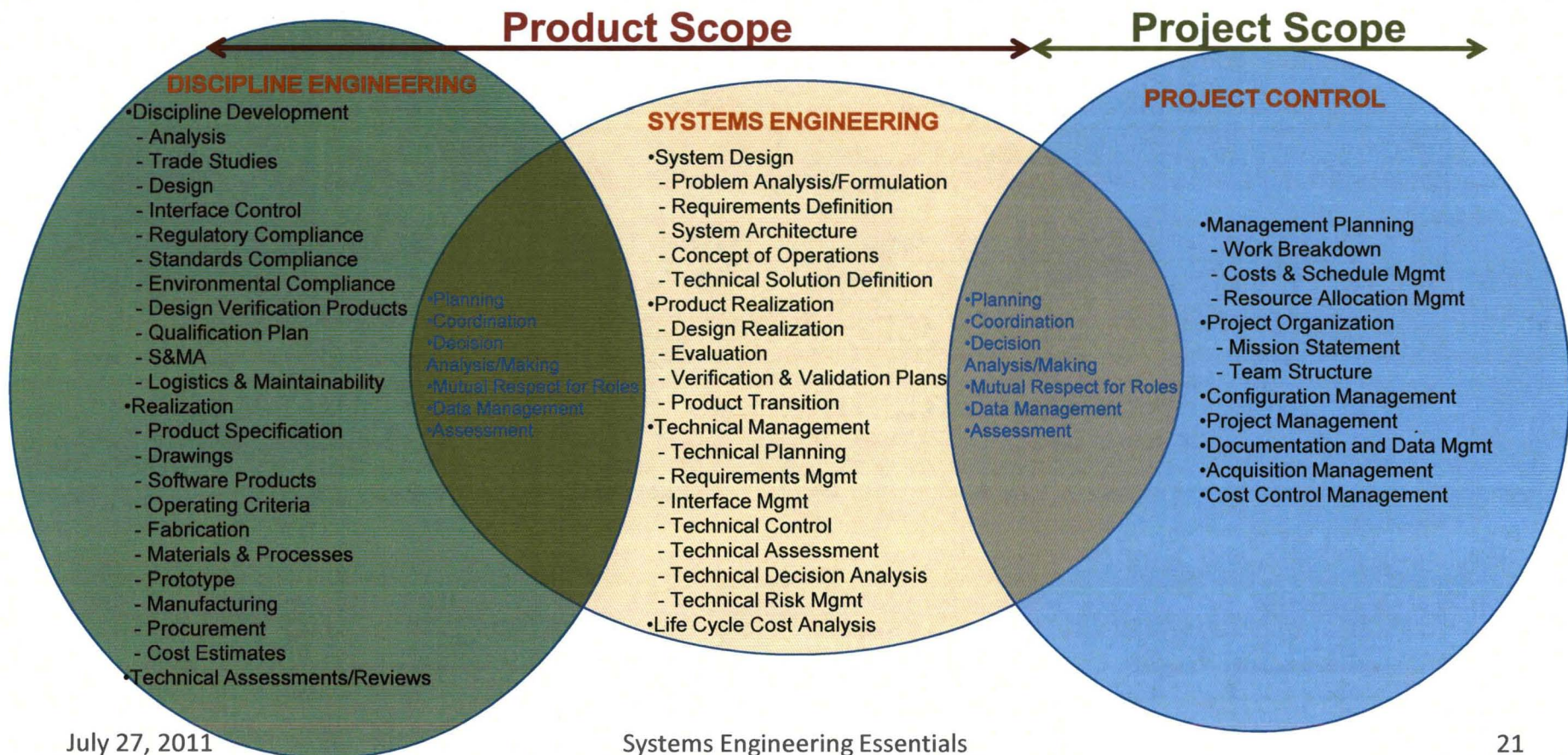


Reference #3.

IV. Who is the Systems Engineer?



- Third, we need to understand the role and responsibilities of the Systems Engineer, the Project Manager and Lead Discipline Engineer.



IV. Who is the Systems Engineer?

- Who is the Systems Engineer?

- It depends on a lot of things...

- The need
 - The team size
 - Complexity of project.
 - Characteristics of team members
 - Personality type (Myers-Briggs Type)
 - Experience of team members
 - Domain Knowledge of team members
 -

SE Essential #4

People who have "systems engineer" in their title, regardless of the modifiers —project, program, flight system, and so on—are responsible for everything. This focus was refreshing because that's the way WE learned the job!

*Gentry Lee,
Jet Propulsion Laboratory*

Commission, not omission. This should be written on the door of every systems engineer. There is no excuse for omission. A systems engineer does not need authority from anyone to investigate anything. The systems engineer's job is the whole space. You go out, you make decisions. If someone tells you to stop, you use your communication skills and listen.

Gentry Lee, Jet Propulsion Laboratory

So, the person who has the Systems Engineer Characteristics and the desire to perform the roles and responsibilities of Systems Engineering is the SE.

V. Where do we apply Systems Engineering?

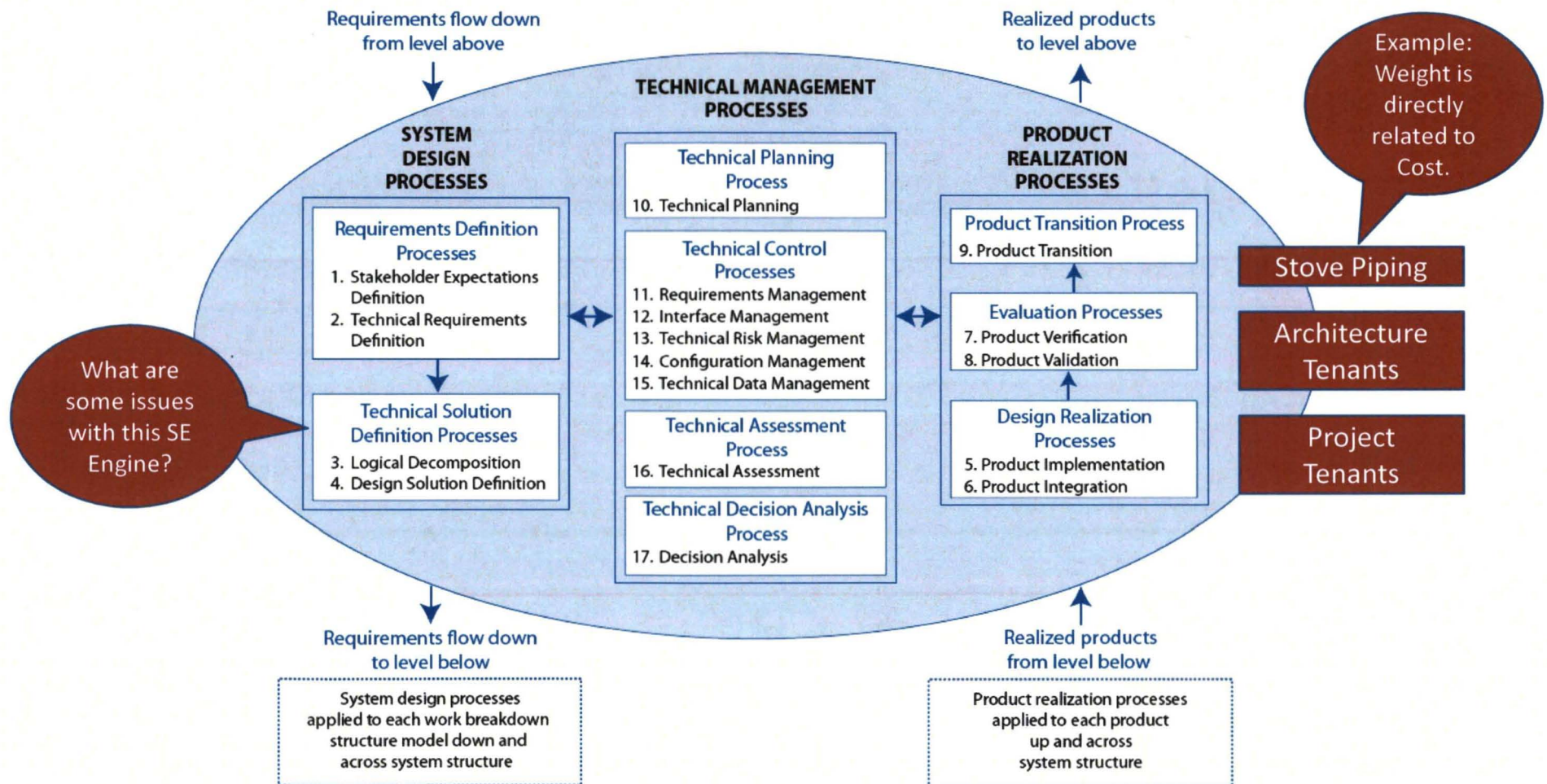


Group Question:

Where do we apply Systems Engineering?

V. Where do we apply Systems Engineering?

NASA Systems Engineering Engine (Chapter 3, Page 5, NSEHB)



VI. What are the important components of Systems Engineering?

- There are dozens of components (Knowledge/Skills) needed for Systems Engineering
- You need knowledge of and Skills on (See NSEHB):

- Customer Needs Analysis / Problem Formulation (page 22-23)
- Define Needs/Goals/Objectives, Define MOE & MOP
- Writing Good Requirements (Appendix-C page 279, page 41)
- Architecture (page 23)
- Concept of Operations/Design Reference Mission (Page 35, DRM)
- Verification and Validation (Appendix-D, E & I)
- Functional and Dynamic Analysis (Appendix- F)
- Integration Plan (Appendix-G)
- System Engineering Management Plan and other Plans (Appendix-J, K & Q)

- Interface Requirements (Appendix-L)
- Configuration Management (CM) Plan (Appendix-M)
- Technology Assessment (Appendix-G)
- Reviews (Appendix-N)
- Statement of Work (SOW) (Appendix-P)
- Assessments/Trade-off Evaluation
- Process Development
- Risk (Page 139)
- Safety & Reliability (Page 45)
-

Each product has a purpose, exploit the essence of each product, not all products are required, so tailor your product selections to your project needs and challenges.

VI. What are the important components of Systems Engineering?

There are dozens of components (Knowledge/Skills) needed for Systems Engineering (Continued)

- You need knowledge of/Skills with:
 - System Engineering/Requirement Management Tools such as:
 - Cradle
 - CORE
 - System Design Modeling Methods such as:
 - Systems Modeling Language (SysML)
 - Unified Modeling Language (UML)
 - Department of Defense Architecture Framework (DoDAF).
 - Quality Tools such as:
 - Total Quality Management (TQM)
 - Quality Function Deployment (QFD)
 - Taguchi Methods.
 - Pugh Matrix
 - Statistics/Risk Analysis

Someone asked me, "What single engineering or mathematical discipline is most important for a systems engineer?" And I answered without batting an eye, "probability and statistics." There is no question about it. Systems engineers who truly understand the underpinnings of probability and statistics quickly separate themselves from those who don't.

Gentry Lee, Jet Propulsion Laboratory

What are the important components of Systems Engineering?

There are a lot of important components to Systems Engineering.

- It begins with Good Sound Engineering. There is no substitute!
- Tailor your products to your project. Focus on essentials.
- Remember, don't limit yourself, use your resources.
- EXPLORE, LEARN, LEARN and LEARN...

"A design that meets specifications is the engineer's view of a good design. However, a design that solves the problem is the customer's view of a good design."

- Dr. G Bunza, Mentor Graphics

VII. How can we incorporate Systems Engineering into our environment?



Group Question:

How can we incorporate Systems Engineering into our environment?

VII. How can we incorporate Systems Engineering into our environment?



On March 26, 1969, Dr. Robert Frosch, former NASA administrator, then Secretary of the Navy, addressed the IEEE Group on Aerospace Systems at the IEEE international convention with a memorable message that systems engineering is an art rather than a science. His closing thoughts are worthy of repeating

Clerk vs
Systems
Thinker!

"As we are now behaving, we are using up our best people in filling out documents for their superiors to read and most of the time no one is running the store."

Engineering
is a Science!

"We have lost sight of the fact that engineering is an art, not a technique; a technique is a tool. From time to time I am briefed on the results of a systems analysis or systems engineering job in a way that prompts me to ask the questions: Do you like it? Is it harmonious? Is it an elegant solution to the real problem? For an answer I usually get a bland expression that suggests I have just said something obscene."

Tools, GIGO!

"We must bring back the sense of art and excitement back into engineering. Talent, competence and enthusiasm are qualities of people who can use tools; the lack of these characteristics usually results in people who cannot even be helped by techniques and tools. We can all do better."

What are the key points of this message?

VII. How can we incorporate Systems Engineering into our environment?

SE Essential #7

How can we incorporate Systems Engineering into our environment?

There are several ways to incorporate Systems Engineering in your environment.
However,

- It begins with **YOU!** JUST DO IT! (Intrinsic)
 - Learn, get training.
 - Communicate
 - Create SE habits (Just ask **WHY?** 5x)
 - Empower your self
 -
- Incorporate into your organizational policy. (Extrinsic)
 - Management needs to fully embrace Systems Thinking
 - Management has to give the Systems Engineer authority.
 - Management needs to clearly delineate roles and responsibilities.
 -

Conclusion

- I. Why do we need Systems Engineering?
- II. What is Systems Engineering?
- III. When do we use Systems Engineering?
- IV. Who is the Systems Engineer?
- V. Where do we apply Systems Engineering?
- VI. What are the important components of Systems Engineering?
- VII. How can we incorporate Systems Engineering into our environment?

But before we finish, one more thing.....



Group Question:

What does it mean to give 100%?

Exam - Solution



What does it mean to give 100%?

Mathematical Proof:

1. Using the English Alphabet,
Let A=1, B=2, ...
2. Convert word to numerical
number and sum word series.
3. There are three words I would like
to focus on
 1. Knowledge
 2. Hardwork
 3. ?

A	1	N	14
B	2	O	15
C	3	P	16
D	4	Q	17
E	5	R	18
F	6	S	19
G	7	T	20
H	8	U	21
I	9	V	22
J	10	W	23
K	11	X	24
L	12	Y	25
M	13	Z	26

Questions



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Systems Engineering Essentials

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